National Aeronautics and
Space Administration

BPS
BIOLOGICAL AND
PHYSICAL SCIENCES

Overview of NASA’s Reduced Gravity Materials Science Research

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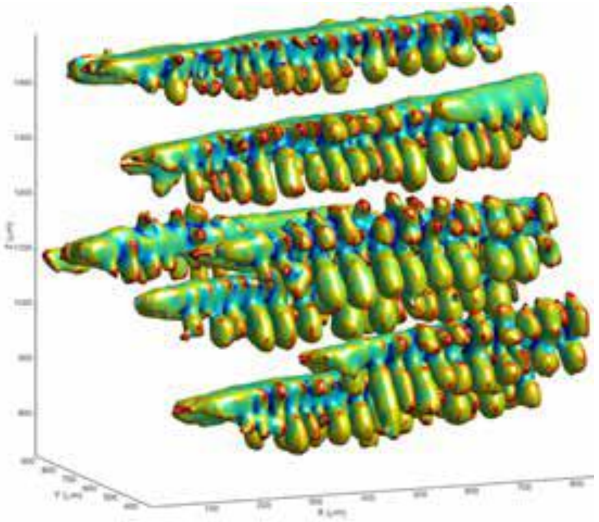
March 22, 2023

What does BPS do?

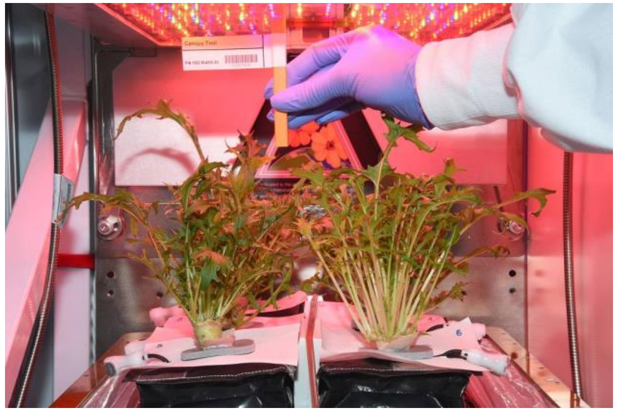
- **We use spaceflight environments to study biological and physical systems.**

- **Examining phenomena under extreme conditions can help us better understand how they function.**

- **This can contribute to significant scientific and technological advancements that enable space exploration and benefit life on Earth.**



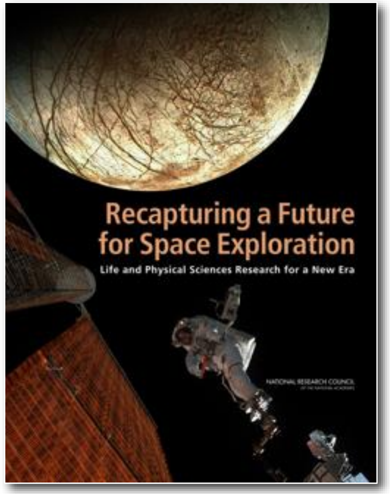
Example Physical Sciences research:
Model of Pb-Sn alloys processed on the ISS

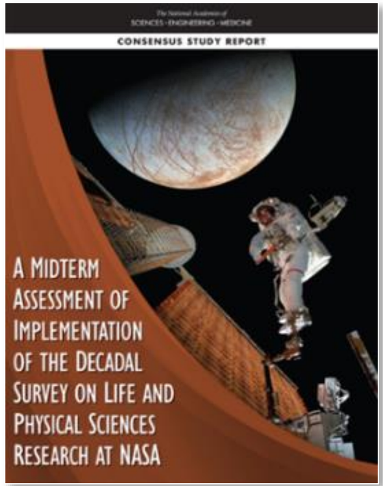


Example of Space Biology research:
Growing plants in space

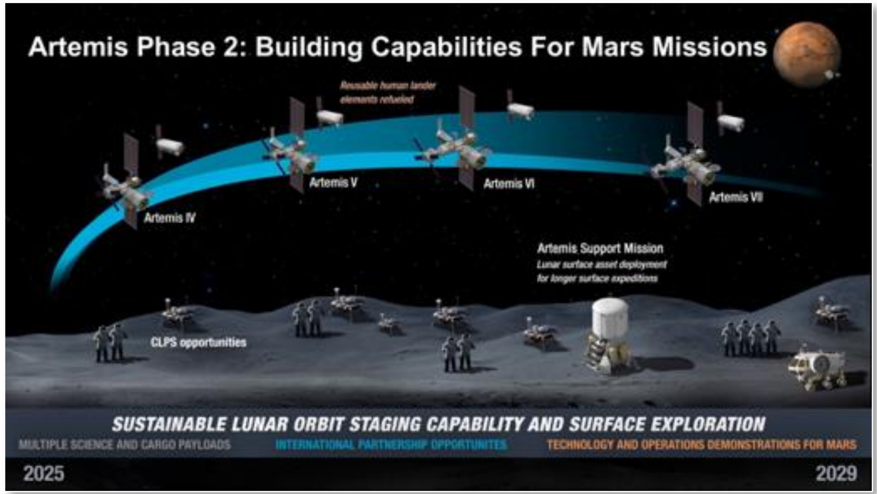
BPS Mission and Goals

- **Pioneer Scientific Discovery**
  - Proactively seek out new ways to expand fundamental scientific knowledge
  - Provide expertise and support to others seeking to utilize space





- **Enable Exploration**
  - Anticipate and investigate critical areas for scientific knowledge and technology development
  - Deliver results to other NASA organizations and industry



BPS Platforms for Research

*Future Platforms

CubeSat

International Space Station

Free Flyers (BION)

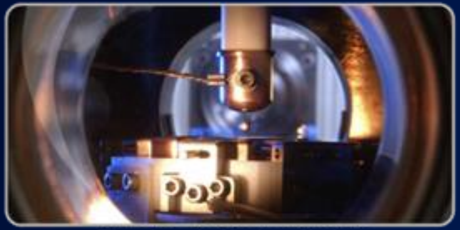
*Lunar Gateway

*Commercial Lunar Lander Services

Drop Tower

Parabolic Flight

Sounding Rocket
Sub-orbital Vehicle



Electrostatic Levitator

*Human Landing System

Rodent Unloading

Centrifuge

Balloon Flight

NASA Space Radiation Lab

NASA Isolation Chamber

NSF Polar Station

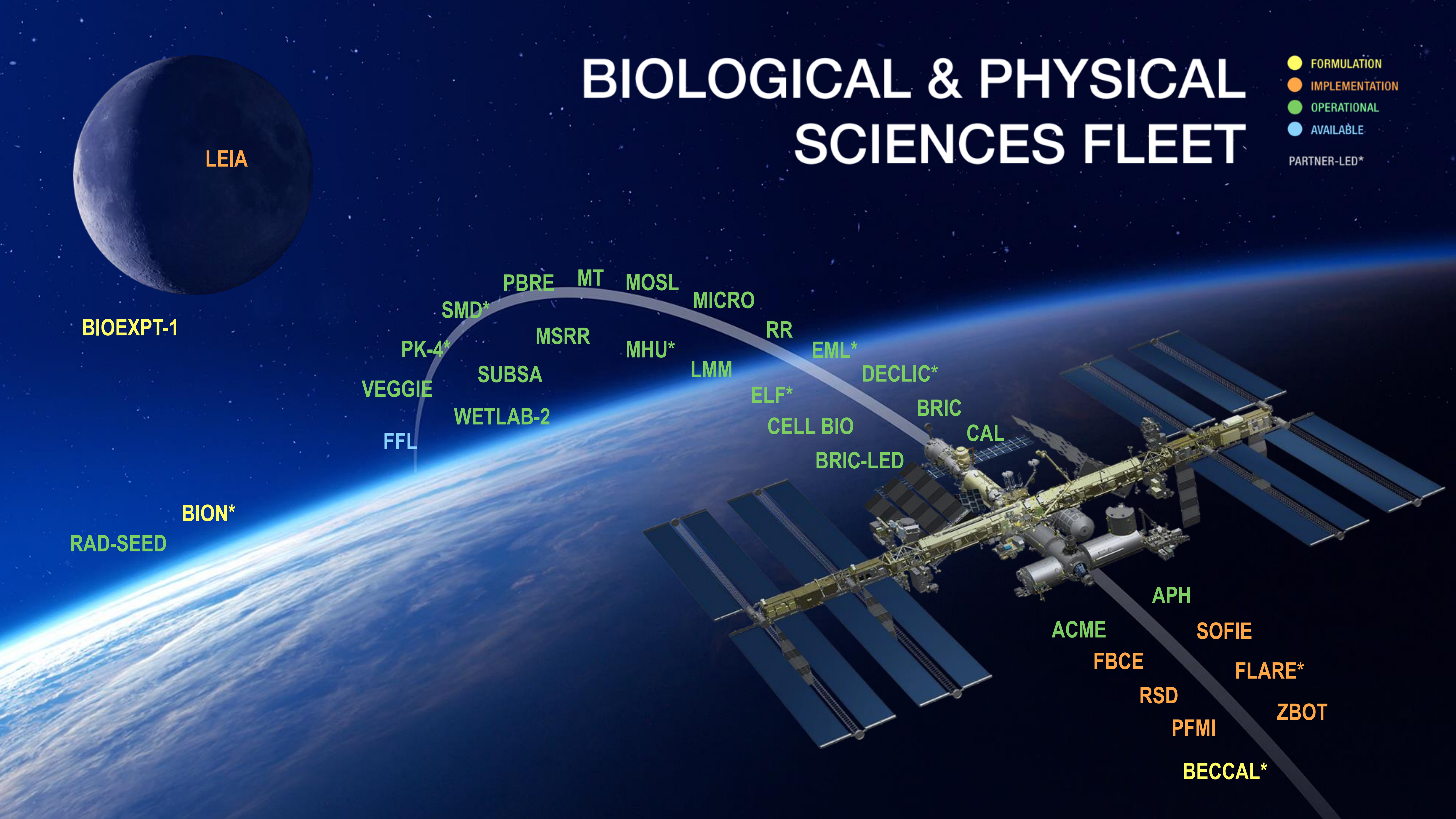
Russian Isolation Chamber

Gravity Vector Averaging

Physical Sciences
Informatics

GeneLab

BIOLOGICAL & PHYSICAL SCIENCES FLEET

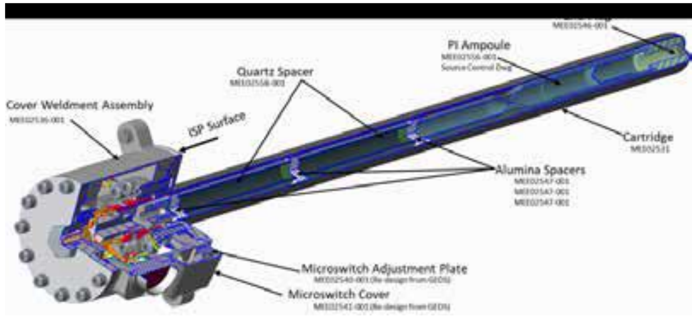


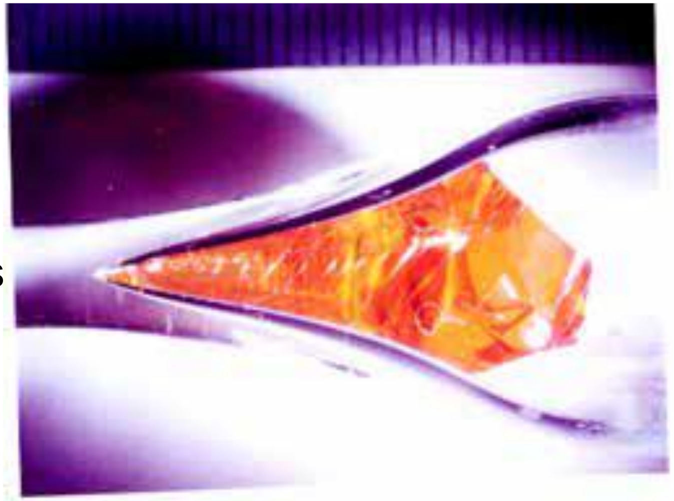
Solidification – High Temperature

Materials Science Research Rack (MSRR) Materials Science Laboratory (MSL) Low Gradient Furnace (LGF)

Sample Cartridge Assemblies (SCA) for the PIs to perform their science

- **Rand German, San Diego State**
  - Objective: Understand the underlying scientific principles to predict density, size, shape, and properties for liquid phase sintered bodies over a broad range of compositions.
- **Ching-Hua Su, NASA MSFC**
  - Objective: Evaluate the effects of gravity on Physical Vapor Transport (PVT) containerless growth processes of semiconductors. Microgravity PVT-grown semiconductors could provide improved crystalline quality and electro-optical properties.
- **Doug Hofmann, NASA JPL**
  - Objective: Develop tungsten-reinforced bulk metallic glass (BMG) matrix composites and demonstrate wear resistance as compared to samples made on the ground.

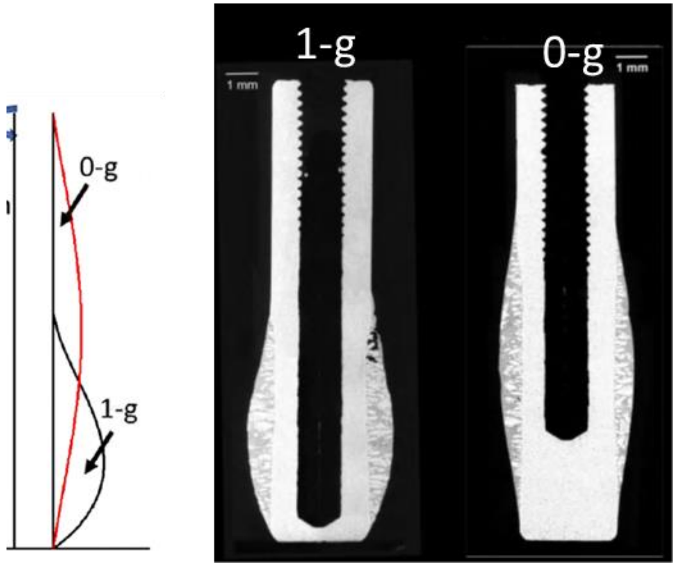




Solidification – Mid Temperature

The Solidification Using a Baffle in Sealed Ampoules (SUBSA) hardware is a furnace that can heat samples up to 850°C for a variety of materials science experiments, and there are currently 3 NASA-funded Investigators with upcoming SUBSA experiments:

- **Dusan Sekulic, University of Kentucky**
  - Objective: Better understand processing kinetics (enhanced wetting, spreading, capillarity) of brazing in low-g environments.
- **Christoph Beckermann, University of Iowa**
  - Objective: Improve the understanding of the columnar-to-equiaxed transition (CET) during solidification of metal alloys.
- **Peter Voorhees, Northwestern University**
  - Objective: Given the importance of dendrite fragmentation on the presence and location of a CET, examine the roles of melting and capillarity induced pinching on dendrite arm fragmentation, retraction and coalescence during cooling.

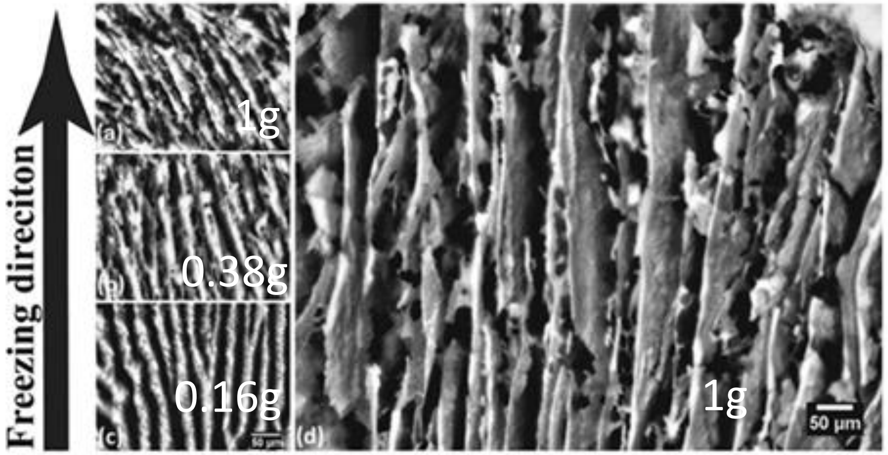


As expected, the wetting distance under the 0-g condition is larger than that under 1-g situation, and surface profile changes from a hanging bag-like shape in 1-g to a symmetric shape in 0-g.

Solidification – Low Temperature

The Pore Formation and Mobility Investigation (PFMI) hardware will melt samples of a transparent modeling material, e.g. succinonitrile and succinonitrile water mixtures. There are currently two Investigators with upcoming PFMI experiments:

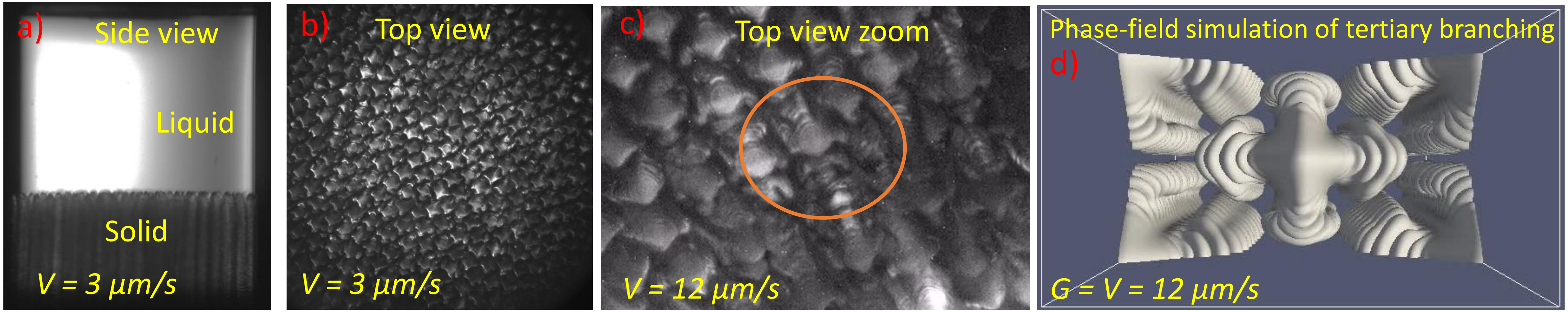
- **David Dunand, Northwestern University**
  - Objective: Improve understanding of solidification behavior of freeze cast materials, which will allow for the development of improved processing techniques.
  - Potential applications include high strength, low weight materials.
- **Ulrike Wegst, Northeastern University**
  - Objective: Investigate the underlying physics of forming complex scaffolds using the freeze casting methodology.
  - Potential applications include lightweight structural materials as well as scaffolds for peripheral nerve repair.



Longitudinal cross-sections of sintered TiO_2 samples sintered from 20 wt% TiO_2 aqueous suspensions directionally solidified under (a) terrestrial, (b) Martian, (c) lunar, and(d) microgravity conditions.

Solidification – Transparent Alloys

- **Device for the study of Critical Liquids and Crystallization –Directional Solidification Insert (DECLIC-DSI) is a facility offering unique capability for 3D *in situ* imaging of the solid-liquid interface dynamics during directional solidification.**
- **Imaging is made possible using transparent alloys such as succinonitrile (SCN)-0.46wt% camphor that solidify the same way metals do and form similar microstructures.**
- **Dr. Alain Karma, Northeastern University (talk by Ji *et al* in this session)**
  - Objective: Model the spatiotemporal evolution of cellular and dendritic array structures.
  - Improved understanding of microstructure formation provides insights enabling the development of advanced structural materials of commercial importance.



Recent publication: Song *et* al, Nature Communications *in press* (2023)

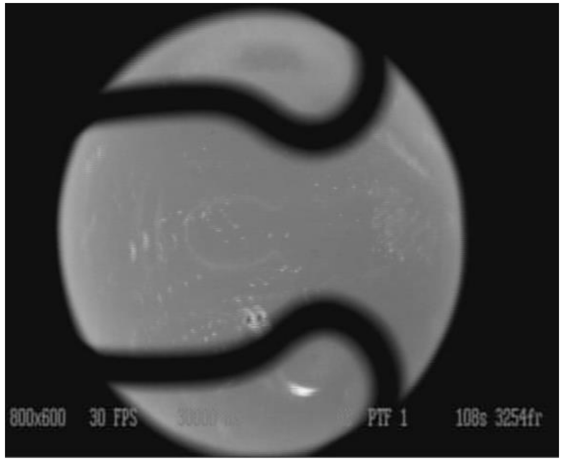
Thermophysical Properties

International Space Station Electromagnetic Levitator (ISS-EML)

- **A multi-user facility for the melting and solidification of conductive metals, alloys, or semiconductors in ultra-high vacuum, or in high-purity gaseous atmospheres.**
- **The heating and positioning of the sample are accomplished using electromagnetic fields generated by a coil system.**
- **Installed in the European space laboratory Columbus.**

There are currently 3 US PIs with experiments on the ISS-EML

- **Robert Hyers, Worcester Polytechnic Institute**
  - Objective: Investigate the thermophysical properties of high-temperature materials used for modeling of material production processes, e.g. additive manufacturing, welding, and casting.
- **Kenneth Kelton, Washington University in St. Louis**
  - Objective: Correlate the nucleation kinetics with the local structure of a liquid alloy by measuring its thermophysical properties. Applications include bulk metallic glass materials.
- **Douglas Matson, Tufts University**
  - Objective: Investigate the effect of fluid flow on the solidification path of aerospace alloys, and to measure the thermophysical properties of high-temperature materials. Applications include turbine blades, industrial welding, automobile components.



Thermophysical Properties

JAXA Electrostatic Levitation Furnace (ELF)

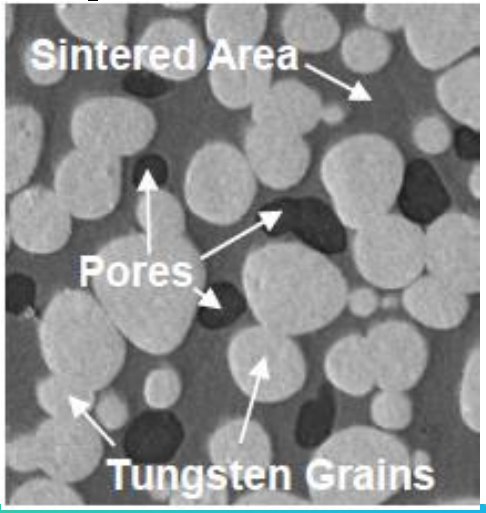
- **Materials science facility for thermophysical properties (e.g. density, surface tension, and viscosity) measurement of molten metals, alloys, glasses, and oxides.**
- **Samples are levitated with an electrostatic field and heated with 4 970nm 40W lasers.**
- **ELF is installed in the MSPR-2 (Multi-purpose Small Payload Rack #2) in Japanese Experimental Module “KIBO” in the ISS.**

There are 4 US principal investigators with experiment on the JAXA ELF:

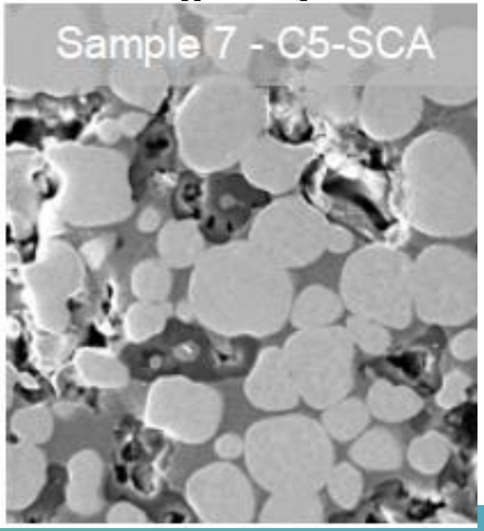
- **Robert Hyers, Worcester Polytechnic Institute**
  - Objective: Advance the understanding of photorefractivity, which has applications in holographic storage, adaptive optics, and phase-conjugate mirrors, using Bi12SiO20and Bi12GeO20.
- **Douglas Matson, Tufts University**
  - Objective: Understand and control the sources of measurement error and to provide a baseline dataset for quantifying uncertainty in measurements (both space-and ground-based).
- **Ranga Narayanan, University of Florida**
  - Objective: Investigate a novel method to determine the interfacial tension, which is a property that impacts industrial processes such as semiconductor crystal growth and additive manufacturing.
- **Richard Weber, Materials Development, Inc**
  - Objective: Develop new understanding of the behavior of oxide liquid, glass and ceramic materials in extreme conditions

Sintering

- **The Gravitational Effects on Distortion in Sintering (GEDS) experiment focuses on understanding the underlying scientific principles to predict density, size, shape, and properties for liquid phase sintered bodies over a broad range of compositions.**
  - The final GEDS sample was processed on Wednesday, June 24th, 2020, on the International Space Station.
- **The GEDS experiment completed heat cycles at over 1200°C to induce liquid phase sintering densification of high-density tungsten alloys.**
  - Liquid phase consists of 50% nickel, 20% tungsten, 15% copper, and 15% manganese.
  - Early results indicate less densification in microgravity, even with liquid formation to assist sintering.
  - Pore sizes are larger and more polygonal in shape
- **The pathway for microstructure-density-distortion is clearly different in microgravity from that on Earth.**



Ground experiment:
Pores and grains are round.



Microgravity Experiment:
Less densification and different pore/grain distribution

Future Opportunities

- **Materials Science NRA**
  - Dependent on the results of the 2023-2032 BPS Decadal Survey
    - To be released later this year
- **Physical Sciences Informatics (PSI)**
  - https://www.nasa.gov/PSI
  - an online database of completed physical science reduced-gravity flight experiments conducted on the International Space Station (ISS), Space Shuttle flights, Free Flyers, or commercial cargo flights to and from the ISS, and from related ground-based studies.
  - Yearly call

Thank you.